Underestimation of Daily Energy Expenditure With the Factorial Method: Implications for Anthropological Research

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ABSTRACT Under field conditions, total daily energy expenditure (TDEE) has generally been estimated using time allocation techniques (the factorial method). However, recent work suggests that the factorial method underestimates TDEE relative to newer, more accurate methods such as doubly labelled water (DLW) and heart-rate (HR) monitoring. This study compares estimates of TDEE obtained by the factorial and HR-monitoring methods for a sample of 61 indigenous (Evenki; 17 males, 44 females) and 32 nonindigenous ("Russian"; 10 males, 22 females) subjects from three communities in Central Siberia. Energy expenditures obtained from the two methods were significantly correlated (r = 0.495; $P < 0.0001$), but the factorial method significantly underestimated TDEE relative to the HR-monitoring technique (8.95 ± 2.73 vs. 8.25 ± 1.34 MJ/d; $P < 0.005$).

Interpopulational analyses of data compiled from this and other studies indicate that the factorial method consistently underestimates TDEE relative to DLW and HR monitoring and that the magnitude of underestimation increases with expenditure levels. Indeed, among sedentary populations, factorial estimates of TDEE converge on those of the other methods, whereas at high activity levels the disparity is quite large. These results imply that the daily energy requirements of many subsistence-level populations have been underestimated, thus providing an overly favorable picture of energy balance. Moreover, it is likely that underrepresentation of TDEE is most problematic in rural societies of the developing world which tend to have high activity levels and great risk of malnutrition. Am J Phys Anthropol 103:443–454, 1997.

Energetic approaches have been widely used in biological anthropology to examine adaptive strategies of human populations (Ulijaszek, 1995). Information on energy expenditure is critical for assessing dietary adequacy and the likelihood undernutrition (James and Schofield, 1990). Additionally, estimates of energy costs for daily activities have been used to assess the efficiency of subsistence behavior among hunting-and-gathering (Hawkes et al., 1982; Smith, 1981), agricultural (Thomas, 1973; Dufour, 1983), and pastoral (Galvin, 1985) societies. Yet,

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while information on activity patterns and energy expenditure provides important insights into the ecology and health of human groups, such data are difficult to obtain on traditional "free-living" populations.

Total daily energy expenditure (TDEE) in anthropological settings has generally been estimated by the factorial method, in which the researcher or subject records the amount of time the subject spends in various activities throughout the day. The activity times are then converted into energetic equivalents. Activity-specific energy costs can be determined by indirect calorimetry while in the field (e.g., Thomas, 1973; Dufour, 1983) or by using standard tables (e.g., Durnin and Passmore, 1967; James and Schofield, 1990; Passmore and Durnin, 1955). TDEE is then determined by summing the energy expended in each activity throughout the day. In 1985, this approach was recommended by the World Health Organization (WHO) as the preferred method for estimating individual and populational energy requirements (FAO/WHO/UNU, 1985).

Recently, however, a number of studies have raised questions about the accuracy of the factorial method for estimating TDEE. For example, work by Roberts et al. (1991) and Haggarty et al. (1994) on American and British men found that the factorial method significantly underestimated TDEE relative to the doubly labelled water method, the technique generally regarded as the most accurate for measuring free-living energy costs. Similarly, studies by Leonard et al. (1995), Spurr et al. (1996), and Dufour et al. (1996) all showed the that the factorial method underrepresented TDEE relative to estimates obtained from daily heart-rate (HR) monitoring. Together, these studies suggest that the factorial method may systematically underestimate TDEE when compared to other, more accurate methods.

The purpose of this research is to further evaluate the utility of the factorial method for estimating TDEE under field conditions. First, we compare estimates of TDEE obtained by the factorial and HR-monitoring methods for men and women of two different ethnic groups (indigenous Evenki and nonindigenous Russians) living in rural communities of Central Siberia. Next, interpopulational analyses are presented using these and previously published data to examine patterns of bias associated with the factorial method. The implications of these results for our understanding of energy dynamics in subsistence-level human populations are then discussed.

METHODS

Sample

This research was conducted among indigenous (Evenki) and nonindigenous (Russian) subjects living in three communities from the Baykit District of the Stony Tunguska region of Central Siberia—Surinda, Poligus, and Baykit (see Fig. 1). Both Surinda and Poligus are relatively small villages, which have remained as the administrative centers for several Evenki reindeer-herding brigades (Leonard et al., 1994). As of 1994, the populations of Surinda and Poligus were 613 and 481, respectively. According to governmental records, 95% of the Surinda population was indigenous (largely Evenki), as compared to 48% in Poligus. In contrast, Baykit, the district capital, is a larger and more urbanized town. According to the 1994 census, the population of Baykit was 5,187, most of whom were nonindigenous (93%).

Anthropometric, dietary, activity recall, and HR data were collected on a sample of 61 Evenki (17 males, 44 females) and 32 Russian (10 males, 22 females) subjects. The male subjects ranged in age from 13–57 years, whereas the females ranged from 14–59. The mean ages of the Evenki and Russian subjects do not significantly differ in either sex. All data were collected in the community health posts from July to September of 1995. The research protocol was approved by the Human Subjects Review Committee of the University of Guelph.

Anthropometry

Anthropometric dimensions included stature (in centimeters), body weight (in kilograms), and skinfold measures (in millimeters) at the triceps and subscapulum. Stature was measured to the nearest millimeter using a portable field anthropometer, and body mass was measured to the nearest 0.5 kg using a standing scale (Seca Corp., Colum-

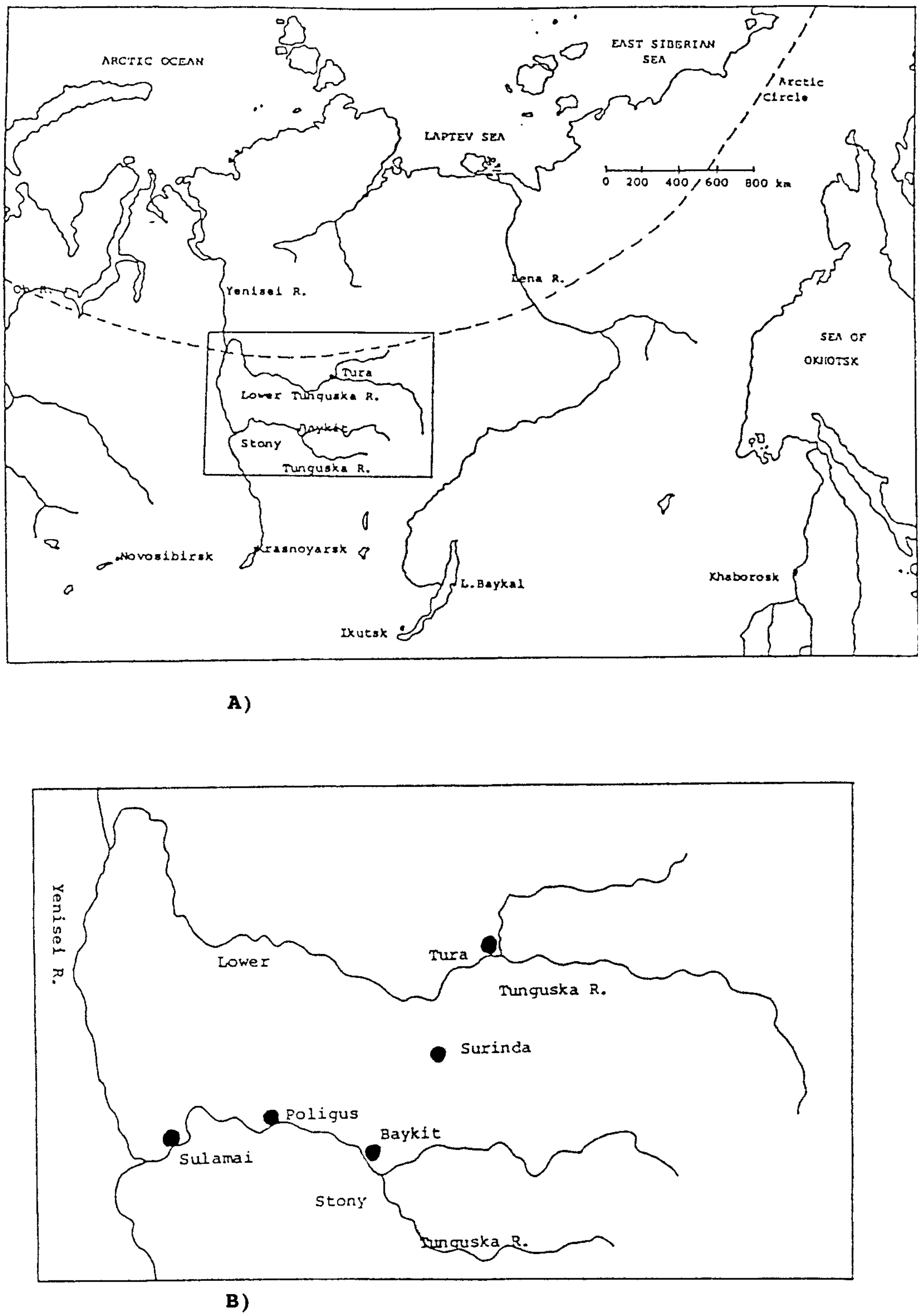

Fig. 1. Map showing the locations of the Stony Tunguska region within Central Siberia (**A**) and the three study communities—Surinda, Poligus, and Baykit (**B**). Modified from Katzmarzyk (1993).

TABLE 1. Activity categories used for estimating energy expenditure from time allocation data

Activity category	PAR[1]	Selected examples
Sleep	1.0	
	1.2	Sitting eating, relaxing
Light	1.4	Visiting friends, watching TV, boiling water
	1.6	Washing, dressing, washing dishes, sewing, walking with no load
Moderate	2.1	Household chores, cooking food, feeding animals
	2.8	Washing clothes, picking fruit, sweeping floor
Heavy	3.8	Carrying firewood, carrying water
Very heavy	5.1	Running; walking with a load (20 kg)

[1] PAR, physical activity ratio = [energy cost of the activity/basal metabolic rate].

bia, MD). Skinfold measurements were taken with Lange callipers (Cambridge Scientific, Cambridge, MD) and were recorded to the nearest 0.5 mm. All measurements were taken by a single observer (W.R.L.) using the techniques described in Lohman et al. (1988).

Energy expenditure

The factorial and HR-monitoring methods were used to assess TDEE for the same day on each subject.

Factorial method. A 24 h activity recall was administered to each subject by E.I. and V.A.G. Each subject was asked about the times that he or she awoke and went to sleep and was then queried about activities during half-hour blocks of his or her waking day.

In coding the data, activities were divided into eight major categories as derived from James and Schofield (1990) and outlined in Table 1. Each category was assigned a physical activity ratio (PAR) reflecting the energy cost as a multiple of basal metabolic rate (BMR). Basal requirements for each subject were calculated from body weight using age- and sex-specific regression equations compiled in the WHO's most recent protein and energy recommendations (FAO/WHO/UNU, 1985). The amount of time spent in activities of each category was then multiplied by the energetic cost of the activity level and summed to obtain an estimate of TDEE.

Heart-rate monitoring. Energy expenditure (EE) from HR monitoring was assessed using the flex-HR technique of Spurr and colleagues (1988). With this method, individual HR vs. expenditure relationships are first established for each subject before having them wear an HR monitor for an entire active day. Heart rates were recorded with a Polar Vantage XL HR monitor (Polar Electro, Stamford, CT). EE (kilojoules/minute) for basal, resting, and exercising conditions was determined using the Aerosport TEEM 100 Metabolic System (Aerosport Inc., Ann Arbor, MI). The oxygen (O_2) and carbon dioxide (CO_2) analyzers were calibrated with external air and tanks of compressed gas containing 16.02% O_2 and 5.03% CO_2 (Scott Specialty Gases, Troy, MI). Expired volumes were measured using pneumotachometers that were calibrated with a 3 liter syringe (Hans Rudolph, Inc., Kansas City, MO). Energy costs for the basal and resting conditions were measured using the low flow pneumotach heads, whereas exercising energy costs were monitored with the medium flow head.

During the evening prior to the metabolic measurements, subjects came into the health post and were informed of the research protocol. Additionally, demographic and dietary information were collected on each subject. Subjects were also given a chance to familiarize themselves with the equipment (e.g., HR monitors, mouthpieces, nose clips). After the briefing session, the subjects slept overnight in the health post.

Basal metabolic rates were measured shortly after the subjects arose the following morning. All subjects had been in a fasted state for at least 10 h when measured, and, when necessary, a portable space heater was used to heat the room to insure thermoneutral conditions. Basal energy costs were determined as the average of the final 8 min of measurement, after the subject had become accustomed to the apparatus, as evidenced by stabilization of the HR, oxygen consumption (VO_2), and respiratory quotient (RQ) values. Following the basal measurements, energy costs of three resting positions (lying, sitting, and standing) were measured for 3 min each. Resting metabolic rate (RMR) was determined as the average costs for those three positions.

TABLE 2. Anthropometric dimensions for male and female Evenki and Russian subjects of the Baykit District of Central Siberia[1]

Sample	n	Age (years)	Weight (kg)	Stature (cm)	BMI (kg/m^2)	Sum skin[2] (mm)
Males						
Evenki	17	31.5 ± 11.4	53.9 ± 8.0	159.7 ± 8.5	21.1 ± 2.8	14.2 ± 3.1
Russian	10	35.9 ± 13.5	72.4 ± 14.8**	172.7 ± 7.6***	24.0 ± 3.1*	23.5 ± 6.2***
Total	27	33.1 ± 12.1	60.7 ± 14.1	164.5 ± 10.3	22.2 ± 3.2	17.6 ± 6.3
Females						
Evenki	44	31.3 ± 11.4	51.0 ± 8.3	150.3 ± 5.4	22.7 ± 3.8	34.7 ± 15.0
Russian	22	32.6 ± 13.9	64.7 ± 15.8***	157.7 ± 6.2***	26.0 ± 6.0*	45.4 ± 20.7*
Total	66	31.7 ± 12.2	55.6 ± 13.0	152.8 ± 6.6	23.8 ± 4.9	38.3 ± 17.7

[1] Values expressed as mean ± SD.
[2] Sum of triceps and subscapular skinfold measures.
* Evenki-Russian difference is significant at $P < 0.05$.
** Evenki-Russian difference is significant at $P < 0.01$.
*** Evenki-Russian difference is significant at $P < 0.001$.

HR vs. EE relationships during exercise were assessed while subjects performed a graded stepping test (Fitness Canada, 1986). The steps consisted of a double riser, each 21 cm high, making for a total ascent of 42 cm. Subjects performed a 3 min bout of exercise before proceeding to the next level of the test, each successive level requiring a faster cadence. Each subject continued until at least three bouts had been completed. Energy costs were measured during the final minute of each exercise bout and HR recorded at the 2.5 minute point, once it had stabilized.

An EE-HR relationship for each subject was plotted, and the least squared regression line for the exercising points was calculated. A flex-HR point was determined as the mean of the highest resting HR and the lowest exercising HR.

Once the EE-HR relationship for a subject had been determined, he/she was fitted with a HR monitor which was worn for an entire day. At the completion of the 24 h period, the subject's HR data were directly downlowded to a portable computer. Small gaps in the HR profile during the active day were filled with the average of the HRs on either side of the gap. The recorded HRs were converted to energetic equivalents by comparing them to the subject's EE-HR relationship. HRs above the flex point were converted using the least squared regression line through the exercise points. For HRs at or below the flex, RMR was assigned as the energy cost. Energy expenditure while sleeping was assumed to equal the measured basal metabolic rate (after Goldberg et al., 1988). Total daily energy expenditure was then calculated by summing the active, resting, and sleeping components of the day with the equation TDEE = AEE + REE + SEE, where TDEE is the total daily energy expenditure, AEE is the active energy expenditure (for HRs > flex), REE is the resting energy expenditure (for HRs ≤ flex), and SEE is the sleep energy expenditure.

Statistical methods

Mean differences between the HR and factorial estimates were compared using paired *t*-tests (one-tailed). Pearson product-moment correlations were used to assess the concordance between the two measures of energy expenditure. Agreement between the two methods was also measured using the statistical approach outlined by Bland and Altman (1986). All analyses were performed using SPSS (SPSS, Chicago, IL) version 4.0.

RESULTS

Table 2 compares the anthropometric characteristics of the Evenki and Russian samples. Not surprisingly, Russian men and women are significantly taller, heavier, and fatter than their Evenki counterparts. Russian men are 13 cm taller and almost 20 kg heavier than Evenki men. Among women, the Russian-Evenki differences are over 7 cm in height and almost 14 kg in mass. Even when weight is adjusted for stature using the BMI, the Russians are significantly heavier than the Evenki. Likewise, the Russians are also relatively fatter, as evidenced

TABLE 3. Measures of energy expenditure for Evenki and Russian men and women[1]

Sample	BMR (MJ/d) Measured	BMR (MJ/d) Estimated	TDEE (MJ/d) HR	TDEE (MJ/d) Factorial	PAL HR	PAL Factorial
Males						
Evenki	6.84 ± 1.45	6.31 ± 0.49	9.99 ± 2.82	8.91 ± 1.56*	1.48 ± 0.37	1.41 ± 0.22
Russian	7.92 ± 1.34	7.32 ± 0.87	10.92 ± 2.32	9.89 ± 1.21	1.39 ± 0.25	1.36 ± 0.15
Total	7.24 ± 1.48	6.69 ± 0.81*	10.33 ± 2.65	9.27 ± 1.50**	1.44 ± 0.33	1.39 ± 0.20
Females						
Evenki	5.39 ± 1.03	5.30 ± 0.40	8.45 ± 2.54	7.51 ± 0.88**	1.59 ± 0.50	1.42 ± 0.14**
Russian	5.45 ± 0.79	5.93 ± 0.51**	8.26 ± 2.70	8.48 ± 0.99	1.53 ± 0.52	1.43 ± 0.11
Total	5.41 ± 0.95	5.51 ± 0.53	8.38 ± 2.60	7.83 ± 1.02*	1.57 ± 0.51	1.42 ± 0.13**

[1] Values expressed as mean ± SD.
* Differences between pairs of energy expenditure measures are significant at $P < 0.05$.
** Differences between pairs of energy expenditure measures are significant at $P < 0.01$.

by significantly higher sum of skinfold measures. Comparisons to US normative data for BMI and skinfolds (from Frisancho, 1990) indicate that males of both ethnic groups tend to be relatively lighter and leaner than their female counterparts.

Comparison of the factorial and HR methods

Table 3 presents the metabolic parameters for the Russian and Evenki subjects. Estimates of TDEE using the HR method are significantly higher than those derived by the factorial method (8.95 ± 2.73 MJ (2,139 kcal) vs. 8.25 ± 1.34 MJ (1972 kcal); $P < 0.005$). Daily expenditure levels among males are, on average, 10.33 MJ (2,470 kcal) for the HR method and 9.27 MJ (2,216 kcal) for the factorial method ($P < 0.01$). The differences between the methods are somewhat smaller for females, as the HR method gave an average of 8.38 MJ (2,003 kcal) compared to 7.83 MJ (1,872 kcal) with the factorial approach ($P < 0.05$).

Some of the differences in TDEE between the two methods may reflect the differences between measured and predicted BMR. For the entire male sample, measured BMR is significantly higher than that predicted from the FAO/WHO/UNU (1985) norms (7.24 vs. 6.69 MJ; $P < 0.05$). Among the women, on the other hand, measured BMRs are comparable to the predicted values for the entire sample and significantly lower among the Russians. When the measured rather than the predicted BMRs are used in the factorial estimates, the HR estimates of TDEE remain significantly higher (8.95 ± 2.73 vs. 8.38 ± 2.11 MJ; $P < 0.01$).

Expressing daily energy expenditure as a multiple of basal requirements provides a measure of activity level (i.e., physical activity level (PAL) = TDEE/BMR). The FAO/WHO/UNU (1985) guidelines for energy requirements have suggested that a PAL of 1.4 is necessary for minimum maintenance activities and that those required for light, moderate, and heavy occupational activities are 1.55, 1.78, and 2.10, respectively, in men and 1.56, 1.64 and 1.82 in women. From the data presented in Table 3, we see that men and women of both ethnic groups appear to have relatively sedentary lifestyles. For all four groups, PAL values obtained from the HR method are higher than those of the factorial approach. These differences are statistically significant for Evenki women (PAL = 1.59 vs. 1.42; $P < 0.01$) as well as for the entire female sample (PAL 1.57 vs. 1.42; $P < 0.01$) and the total sample (1.54 vs. 1.41; $P < 0.01$).

The relationship between the factorial and HR estimates of TDEE is presented in Figure 2. Estimates from the two methods are significantly correlated ($r = 0.495$; $P < 0.0001$). The slope of the regression line, however, is significantly shallower than 1 ($b = 0.244 \pm 0.045$), indicating that the factorial method systematically underestimates TDEE in this sample. A comparable pattern is seen when the HR estimates of TDEE are compared to the factorial estimates based on measured BMR. In this latter case the correlation between the HR and factorial esti-

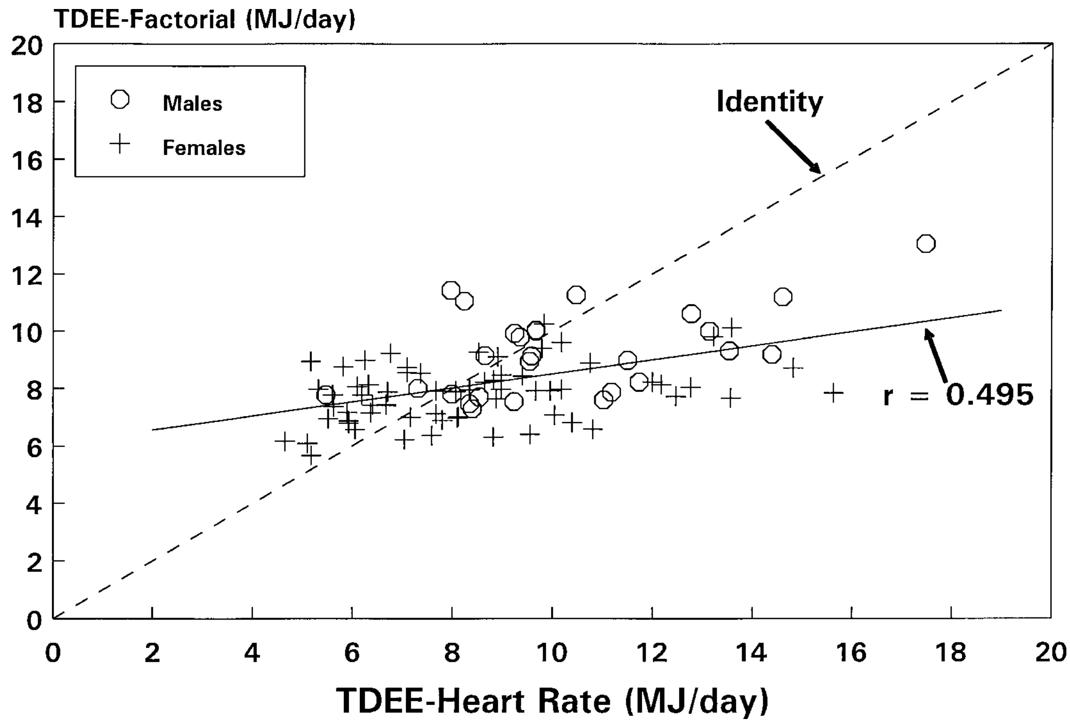

Fig. 2. Relationship between the factorial vs. HR estimates of energy expenditure. Estimates from the two methods are highly correlated (r = 0.495; $P < 0.0001$); however, the slope of the regression is significantly shallower than identity (b = 0.244 ± 0.045; $P < 0.001$).

mates is higher (r = 0.588; $P < 0.0001$), while the slope of the regression is steeper but still significantly less than 1 (b = 0.453 ± 0.065).

Differences between the factorial and HR estimates are examined further in Figure 3, which compares the two techniques using the statistical method developed by Bland and Altman (1986). In this figure, the factorial estimates are those derived using estimated BMRs. For each subject, the difference between the two estimates (factorial − HR) is plotted against their average. The factorial estimates average 0.70 ± 2.37 MJ (167 kcal) less than the HR estimates, an underestimation of about 8%. Additionally, the plot demonstrates that the magnitude of underestimation is significantly correlated with absolute expenditure levels (r = −0.664; $P < 0.001$). This implies that the factorial method does not provide an unbiased estimate of TDEE relative to HR monitoring; rather, the degree of underestimation increases with greater expenditure levels. Indeed, for average TDEEs under 10 MJ/day, there is relatively high concordance between the two methods, with the estimates differing by only 0.5% (.04 MJ). Above 10 MJ, on the other hand, the two methods depart by 29% (3.77 MJ).

Carrying out the Bland-Altman analysis using the factorial estimates based on measured BMR produces similar results. In this case, the factorial estimates are 0.57 ± 2.27 MJ (136 kcal) lower than the HR estimates (~7% underestimation). As with the previous analysis, the degree of underestimation is significantly correlated with absolute expenditures; however, the level of association is more modest (r = −0.309; $P < 0.01$).

Interpopulational comparisons

Table 4 presents PAL estimates compiled from recent studies that have compared the factorial approach to other methods of indirect calorimetry (either DLW or HR monitoring) under free-living conditions. In addition to the information presented here, compara-

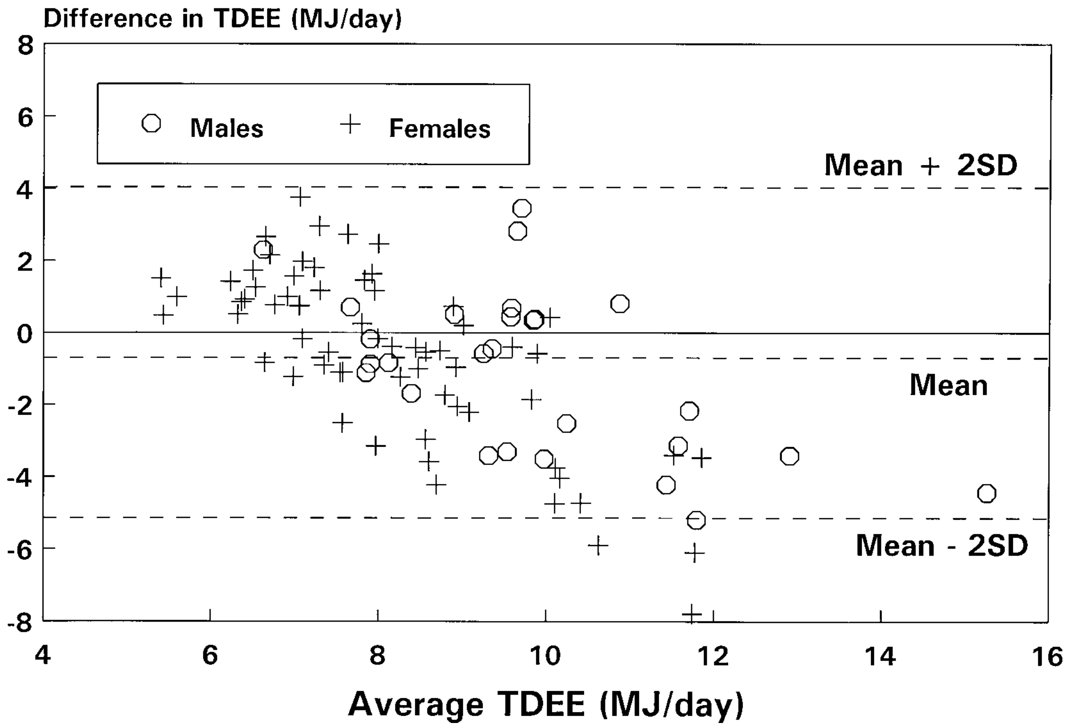

Fig. 3. Difference in energy expenditure (factorial − HR) vs. mean energy expenditure for the HR and factorial methods. The factorial method underestimates TDEE by an average of 0.70 ± 2.37 MJ, and the differences between the methods are significantly correlated with absolute expenditure levels (r = −0.664; $P < 0.001$).

TABLE 4. Comparison of physical activity level (PAL) estimates using the factorial method vs. other methods of indirect calorimetry (DLW or HR monitoring) for selected populations

Group	Sex	n	Comparison method	PAL1[1]	PAL2[2]	Reference
US adults	M	14	DLW	1.56	1.98	Roberts et al. (1991)
British adults	M	17	DLW	1.79	1.96	Haggarty et al. (1994)
Ecuador						
Highland farmers	M	11	HR monitoring	1.95	2.39	Leonard et al. (1995)
	F	11	HR monitoring	1.71	1.97	
Coastal farmers	M	5	HR monitoring	1.43	1.58	Leonard et al. (1995)
	F	5	HR monitoring	1.56	1.62	
Colombia						
Urban adults	F	29	HR monitoring	1.47	1.83	Spurr et al. (1996)
Urban adults	F	23	HR monitoring	1.50	1.90	
Siberia						
Evenki villagers	M	17	HR monitoring	1.41	1.48	Present study
	F	44	HR monitoring	1.42	1.59	
Russian villagers	M	10	HR monitoring	1.36	1.39	Present study
	F	22	HR monitoring	1.43	1.53	
Mean ± SD				1.55 ± 0.18	1.77 ± 0.29*	

[1] PAL1, physical activity level estimate using the factorial method.
[2] PAL2, physical activity level estimate using the DLW or HR-monitoring method.
* PAL estimates different at $P < 0.001$.

tive data were available for samples of American and British men (from Roberts et al. (1991) and Haggarty et al. (1994), respectively), men and women from farming communities of highland and coastal Ecuador (from Leonard et al., 1995), and wage-earning and non-wage-earning urban Colombia women (from Spurr et al., 1996). For all

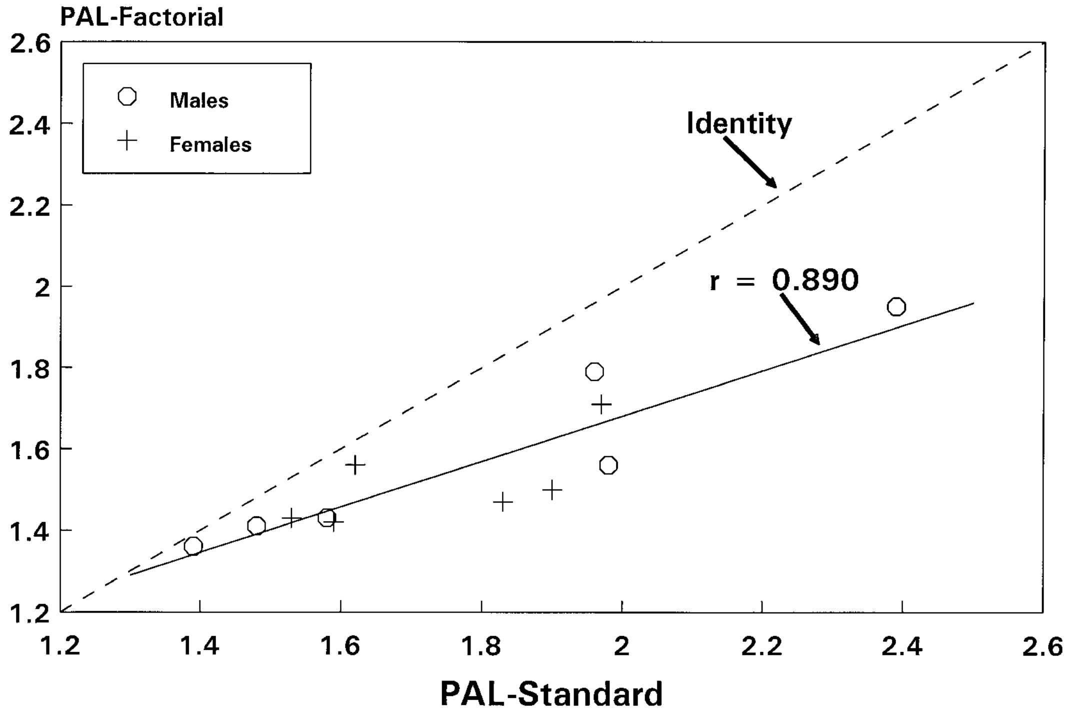

Fig. 4. Relationship between factorial and DLW or HR-monitoring estimates of physical activity level (PAL) for the 12 sex-specific samples presented in Table 4. The factorial estimates of PAL are highly correlated with those derived from the other methods of indirect calorimetry (r = 0.890; $P < 0.0001$); however, the slope of the regression is significantly less than 1 (b = 0.557 ± 0.090; $P < 0.01$).

12 sex-specific samples, the PALs obtained from the factorial method are lower than those derived from the comparator method (either DLW or HR monitoring). On average, the factorial PALs were significantly lower than the HR and DLW estimates (1.55 vs. 1.77; $P < 0.001$).

The data from Table 4 are presented graphically in Figure 4. This plot shows that despite the systematic pattern of underestimation with the factorial approach, the factorial estimates are highly correlated with those derived from the DLW and HR methods (r = 0.890; $P < 0.0001$). The slope of the regression line, however, is significantly less than 1 (b = 0.557 ± 0.090; $P < 0.01$), again suggesting that the degree of underestimation is greater at higher expenditure levels. This analysis suggests that at very low activity levels (PALs ≤ 1.3), the factorial estimates converge with those of other methods. At moderate to high activity levels (PALs ≥ 1.7), on the other hand, there is substantial underestimation with the factorial approach.

DISCUSSION

Results of the present study are consistent with much recent work suggesting that the factorial method systematically underestimates total daily energy expenditure in free-living populations (see Dufour et al., 1996; Haggarty et al., 1994; Leonard et al., 1995; Roberts et al., 1991; Spurr et al., 1996). There are a number of possible explanations for the apparent disparity between estimates obtained from the factorial approach relative to other, more accurate methods of assessing TDEE. One source of the bias may be the use of activity recalls rather than direct observations for determining the factorial estimates. However, this does not appear to be the entire explanation. Spurr et al. (1996) found substantial underestimation of TDEE even with factorial estimates that are based on continuous minute-by-

minute observations. Interpopulational variation in BMR is widely documented (e.g., Roberts, 1978; Henry and Rees, 1991; Rode and Shephard, 1995) and may contribute to underestimation of TDEE with the FAO/WHO/UNU's (1985) factorial method. Results presented here suggest that differences in TDEE between the two methods are partially attributable to differences in BMR. Using measured rather the predicted BMRs in the factorial estimates resulted in a 19% reduction in the average level of underestimation; however, these factorial estimates remained significantly lower than those obtained from the HR method. Additionally, in our previous study among Ecuadorian farmers (Leonard et al., 1995), we utilized predicted BMRs for both our HR and factorial estimates and still found significant differences between the methods. Thus, it appears that variation in BMR cannot entirely explain the systematic underestimation of TDEE by the factorial method.

It has also been suggested that because much of the standard reference data for activity costs have been derived on Western populations (e.g., Durnin and Passmore, 1967; FAO/WHO/UNU, 1985; James and Schofield, 1990) these data cannot be effectively applied to populations of different social and ethnic backgrounds (Dufour et al., 1996; Durnin, 1990; Spurr et al., 1996). Similarly, Spurr et al. (1996) found that among Colombian women the FAO/WHO/UNU's (1985) values for several activities gave energy costs that were significantly lower than those measured by indirect calorimetry. In contrast, Katzmarzyk et al. (1996) found that in three subsistence-level populations (Siberians and highland and coastal Ecuadorians), the energy costs of a submaximal stepping exercise did not significantly deviate from those predicted from Canadian normative values. These authors suggested that the underestimation of TDEE with the factorial method in traditionally living populations may largely reflect error in estimating energy costs at rest (i.e., lying, sitting, standing) rather than during activity and exercise.

Regardless of what the source of bias is, the current results have enormous implications for research in human population biology and nutrition. These findings seem to confirm the suspicion of Durnin (1990) and others who have suggested that low expenditures reported for many free-living populations are physiologically unlikely. In the anthropological literature, for example, extremely low TDEE and PAL estimates have been reported for such populations as the !Kung San foragers of the Kalahari (Lee, 1979; Leslie et al., 1984), the Turkana pastoralists of Kenya (Galvin, 1985; Little and Gray, 1990), and the Quechua agropastoralists of Peru (Leonard, 1992; Thomas, 1973). In light of the present findings, it is probable that the daily energy requirements of these groups have been underestimated, thus providing an overly favorable picture of population energy balance.

The problem of underestimating energy needs (and overestimating dietary adequacy) is likely to be most acute among highly active groups. This study, as well as those of Haggarty et al. (1994) and Leonard et al. (1995), demonstrated that the level of underestimation of the factorial method increases with TDEE. It would therefore seem that the errors associated with the factorial method will be greatest when applied to rural developing-world populations, who tend to have higher daily activity levels than populations of the developed world (see Schulz and Scholler, 1994). This implies that the WHO's recommended method for estimating TDEE is most likely to underrepresent the problem of energy stress among those populations that are at greatest risk for malnutrition (i.e., rural, developing-world agrarian societies).

Beyond these issues of daily energy requirements and energy balance, the present results also have implications for examining the efficiency of human subsistence regimes. For example, the application of optimal foraging theory for understanding subsistence behavior among hunting and gathering populations has generally relied on standard reference data such as Durnin and Passmore (1967) to determine the energetic costs and benefits of exploiting different resources (see Smith, 1981; Winterhalder, 1981). Potential bias in estimating the energy costs of foraging tasks should therefore tend to skew calculations of the relative

benefits of exploiting different potential resources, leading to errors in predictions about which resources are to be included in an "optimal diet."

Yet, despite the clear limitations in the factorial method, it does appear to effectively determine relative activity levels within and among different populations. The high correlations between energy expenditure estimates obtained by the factorial and the DLW or HR methods indicate that the factorial approach is able to rank relative daily expenditure levels across individuals and groups. Although the factorial method may not be able to quantify TDEE with a high degree of accuracy, it can effectively discriminate groups that are highly active from those that are moderately active and sedentary.

In conclusion, this study has shown that the factorial approach significantly and systematically underestimates total daily energy expenditure both within and between human populations relative to other methods of indirect calorimetry used with free-living conditions. The degree of underestimation is related to absolute expenditure levels, such that relatively greater bias is seen at higher TDEEs. These results raise concern about the utility of the WHO's recommended methodology for assessing human energy needs, since it may tend to mask the severity of energy stress evident in populations of the developing world. They also suggest that estimates of dietary adequacy reported for many traditional, subsistence-level populations must be viewed with some caution. While the factorial method does effectively sort groups into relative activity levels, it underrepresents TDEE, especially at high expenditure levels.

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